

Chapter 2. Oceanographic Conditions

INTRODUCTION

The City of San Diego collects a comprehensive suite of oceanographic data from offshore ocean waters surrounding both the Point Loma and South Bay Ocean Outfalls (PLOO and SBOO, respectively) to characterize conditions in the region and to identify possible impacts of wastewater discharge. Measurements of water temperature, salinity, density, light transmittance (transmissivity), dissolved oxygen (DO), pH, chlorophyll *a*, and colored dissolved organic matter (CDOM) are important indicators of physical and biological oceanographic processes (e.g., Skirrow 1975) that can impact marine life (Mann 1982, Mann and Lazier 1991). In addition, because the fate of wastewater discharged into marine waters is determined not only by the geometry of an ocean outfall's diffuser structure and rate of discharge, but also by oceanographic factors that govern water mass movement (e.g., water column mixing, ocean currents), evaluations of physical parameters that influence the mixing potential of the water column are important components of ocean monitoring programs (Bowden 1975, Pickard and Emery 1990). For example, the degree of vertical mixing or stratification, and the depth at which the water column is stratified, indicates the likelihood and depth of wastewater plume trapping. Further, previous studies have shown that wastewater plumes can often be identified by having lower salinity and higher CDOM values than background conditions (e.g., Terrill et al. 2009, Todd et al. 2009).

In nearshore coastal waters of the Southern California Bight (SCB) such as the South Bay outfall region, oceanographic conditions are strongly influenced by several factors, including (1) global and regional climate processes such as El Niño/La Niña, Pacific Decadal and North Pacific Gyre oscillations that can affect long-term (~10–20 years) trends (Peterson et al. 2006,

McClatchie et al. 2008, 2009, Bjorkstedt et al. 2010, 2011, NOAA/NWS 2011), (2) the California Current System (CCS) coupled with local gyres that transport distinct water masses throughout the SCB (Lynn and Simpson 1987), and (3) seasonal changes in local weather patterns (Bowden 1975, Skirrow 1975, Pickard and Emery 1990). Southern California weather is classified into a wet or winter season (typically December through February) and a dry summer season (typically July through September) (WRCC 2012), with differences between these seasons affecting oceanographic conditions such as water column stratification and current patterns. For example, storm activity during southern California winters brings higher winds, rain, and waves that often contribute to the formation of a well-mixed, non-stratified water column (Jackson 1986). The chance of wastewater plumes from sources such as the SBOO reaching surface waters is highest during these times since no barriers (temperature, salinity gradients) exist. These winter conditions often extend into spring until the frequency of storms decreases and the transition from wet to dry conditions begins. In late spring the surface waters begin to warm, which results in increased surface evaporation (Jackson 1986). Once the water column becomes stratified, minimal mixing conditions typically remain throughout the summer and early fall months. In the fall, cooler temperatures, along with increases in stormy weather, begin to cause the return of well-mixed water column conditions.

Understanding changes in oceanographic conditions due to natural processes such as the seasonal patterns described above is important since they can affect the transport and distribution of wastewater, storm water and other types of turbidity (e.g., sediment) plumes. In the SBOO region these include plumes associated with tidal exchange from San Diego Bay, outflows from the Tijuana River in California waters and Los Buenos Creek in northern Baja California, storm water discharges, and runoff

from local watersheds. For example, flows from San Diego Bay and the Tijuana River are fed by 1165 km² and 4483 km² of watersheds, respectively (Project Clean Water 2012), and can contribute significantly to nearshore turbidity, sediment deposition, and bacterial contamination (see Largier et al. 2004, Terrill et al. 2009).

This chapter presents analyses and interpretations of the oceanographic data collected during 2011 at fixed monitoring stations surrounding the SBOO. The primary goals are to: (1) summarize oceanographic conditions in the SBOO region, (2) identify potential natural and anthropogenic sources of variability, (3) assess possible influence of the SBOO wastewater discharge relative to other input sources, and (4) determine the extent to which water mass movement or water column mixing affects the dispersion/dilution potential for discharged materials. Results of remote sensing observations (e.g., aerial and satellite imagery) may also provide useful information on the horizontal transport of surface waters (Pickard and Emery 1990, Svejksky 2012). Thus, this chapter combines measurements of physical oceanographic parameters with assessments of remote sensing data to provide further insight into the transport potential in coastal waters surrounding the SBOO discharge site. The results reported herein are also referred to in subsequent chapters to explain patterns of indicator bacteria distributions (see Chapter 3) or other changes in the local marine environment (see Chapters 4–7).

MATERIALS AND METHODS

Field Sampling

Oceanographic measurements were collected at 40 fixed sampling sites arranged in a grid pattern surrounding the SBOO and encompassing an area of ~300 km² (Figure 2.1). These stations (designated I1–I40) are located between about 3.4–14.6 km offshore along or adjacent to the 9, 19, 28, 38 and 55-m depth contours. The stations were sampled monthly over a 3-day period (see Table 2.1). Sites

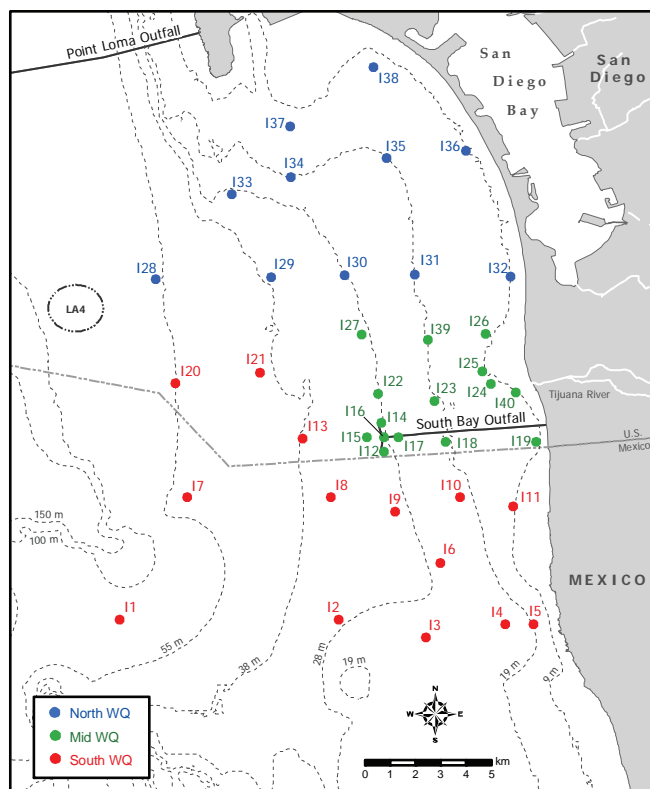


Figure 2.1

Water quality (WQ) monitoring station locations sampled around the South Bay Ocean Outfall as part of the City of San Diego's Ocean Monitoring Program.

were grouped together during each sampling period as follows: “North Water Quality” stations I28–I38 ($n=11$); “Mid Water Quality” stations I12, I14–I19, I22–I27, I39, I40 ($n=15$); “South Water Quality” stations I1–I11, I13, I20, I21 ($n=14$).

Oceanographic data were collected using a SeaBird conductivity, temperature, and depth instrument (CTD). The CTD was lowered through the water column at each station to collect continuous measurements of water temperature, salinity, density, pH, transmissivity (a proxy for water clarity), chlorophyll *a* (a proxy for the presence of phytoplankton), DO, and CDOM. Water column profiles of each parameter were then constructed for each station by averaging the data values recorded in each 1-m depth interval. This data reduction ensured that physical measurements used in subsequent analyses corresponded to discrete sampling depths for indicator bacteria (see Chapter 3). Visual observations of weather

Table 2.1

Sample dates for monthly oceanographic surveys conducted in the South Bay outfall region during 2011. Each survey was conducted over three consecutive days with all stations in each station group sampled on a single day (see text and Figure 2.1 for a list of stations and station locations).

Station Group	2011 Monthly Sampling Dates											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
North WQ	3	3	1	4	11	6	7	22	15	3	7	5
Mid WQ	4	1	2	6	10	8	6	23	14	5	8	6
South WQ	5	2	3	5	12	7	5	24	13	4	9	7

and water conditions were recorded just prior to each CTD cast.

Remote Sensing

Coastal monitoring of the SBOO region during 2011 included remote imaging analyses performed by Ocean Imaging (OI) of Solana Beach, CA. All satellite imaging data collected during the year were made available for review and download from OI's website (Ocean Imaging 2012), while a separate annual report summarizing results for the year was also produced (Svejkovsky 2012). Several different types of satellite imagery were analyzed during the past year including Moderate Resolution Imaging Spectroradiometer (MODIS), Thematic Mapper TM7 color/thermal, and high resolution Rapid Eye images. These technologies differ in terms of their capabilities as described in the "Technology Overview" section of Svejkovsky (2012), but are generally useful for revealing patterns in surface waters as deep as 12 m, depending on conditions (e.g., water clarity).

Data Analysis

With the exception of CDOM, the various water column parameters measured in 2011 were summarized as means of surface (top 2 m) and bottom (bottom 2 m) waters for each month pooled over all stations along each of the 9, 19, 28, 38 and 55-m depth contours. Additionally, data from the 28-m depth contour stations (stations I2, I3, I6, I9, I12, I14, I15, I16, I17, I22, I27, I30, I33) were averaged for each 1-m depth bin by month

to identify seasonal trends. Data were limited to these 13 stations to prevent masking trends that might occur when data from all depth contours are combined. CDOM data were not included in these analyses due to calibration issues with the individual CDOM probes, which make absolute (measured) values unreliable. Because of this limitation, only relative scales are used for CDOM in this report (see below).

For spatial analysis of all parameters, 3-dimensional graphical views were created for each month using Interactive Geographical Ocean Data System software (IGODS), which interpolates data across all depths at each site and between stations along each depth contour. CDOM data were included as part of these spatial analyses using relative values that were not affected by the calibration issues mentioned above. In most cases, the IGODS analyses reported herein are limited to the four monthly surveys most representative of the winter (February), spring (May), summer (August), and fall (November) seasons, and which corresponded to the quarterly water quality surveys conducted as part of the coordinated Point Loma Ocean Outfall and Central Bight Regional monitoring efforts.

Finally, a time series of anomalies for each parameter was created to evaluate significant oceanographic events that have occurred in the region. Anomalies were calculated by subtracting the mean of all 17 years combined (i.e., 1995–2011) from the monthly means for each year. These mean values were calculated using data from just the 28-m depth contour stations, with all water column depths combined.

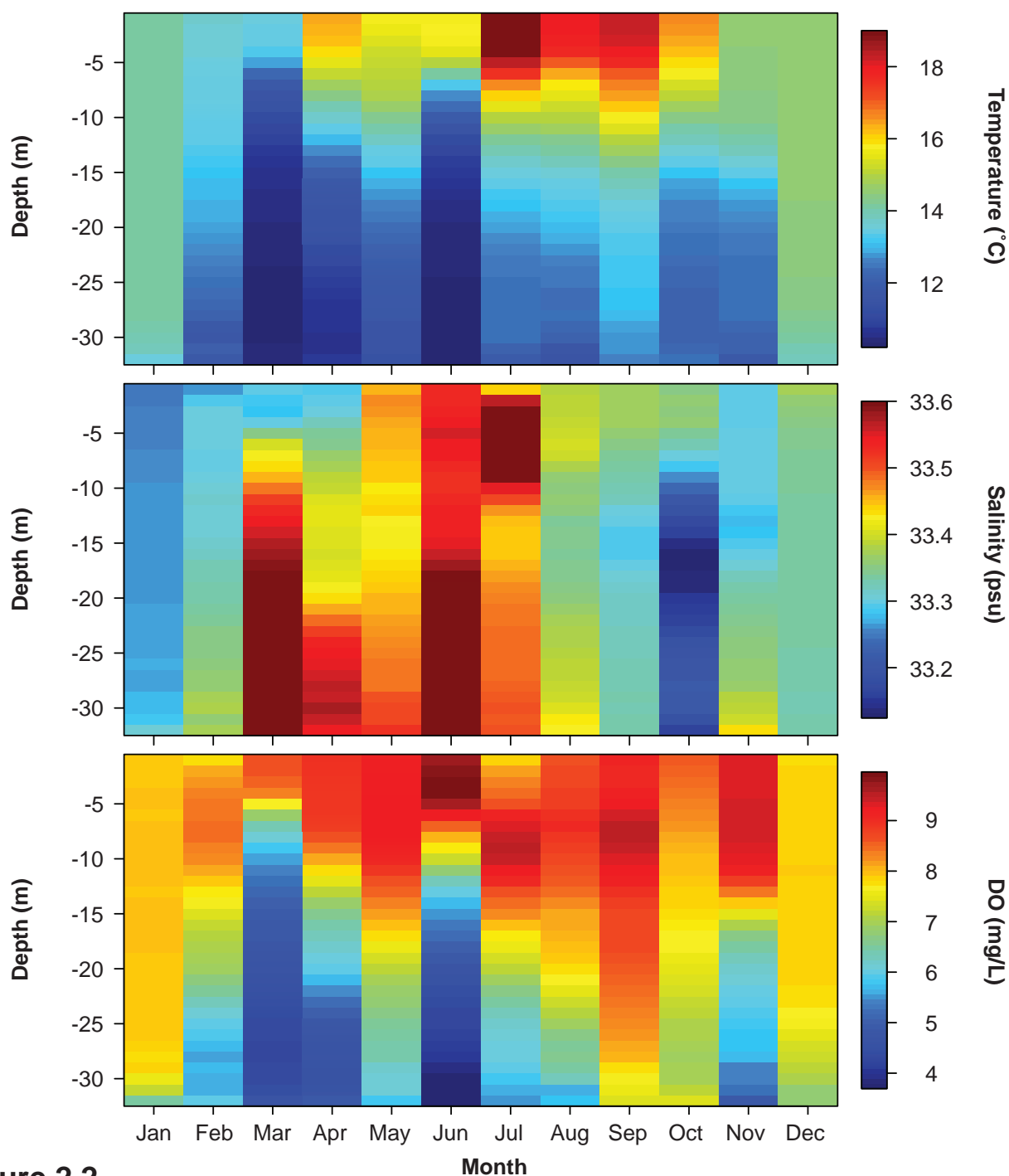


Figure 2.2

Temperature, salinity, dissolved oxygen (DO), pH, transmissivity, and chlorophyll *a* (Chl) values recorded at SBOO 28-m stations during 2011. Data are expressed as mean values for each 1-m depth bin, pooled over all stations.

RESULTS AND DISCUSSION

Oceanographic Conditions in 2011

Water Temperature

Surface temperatures across the entire SBOO region in 2011 averaged from 12.4°C in March to 20.3°C

in July, while bottom temperatures averaged from 10.0°C in March to 15.6°C in August (Appendix A.1). The maximum average surface temperature recorded during the year was ~1° higher than in 2010, and occurred earlier in the year (i.e., July versus October; City of San Diego 2011a). Water temperatures varied by season as expected. For example, colder bottom waters likely indicative

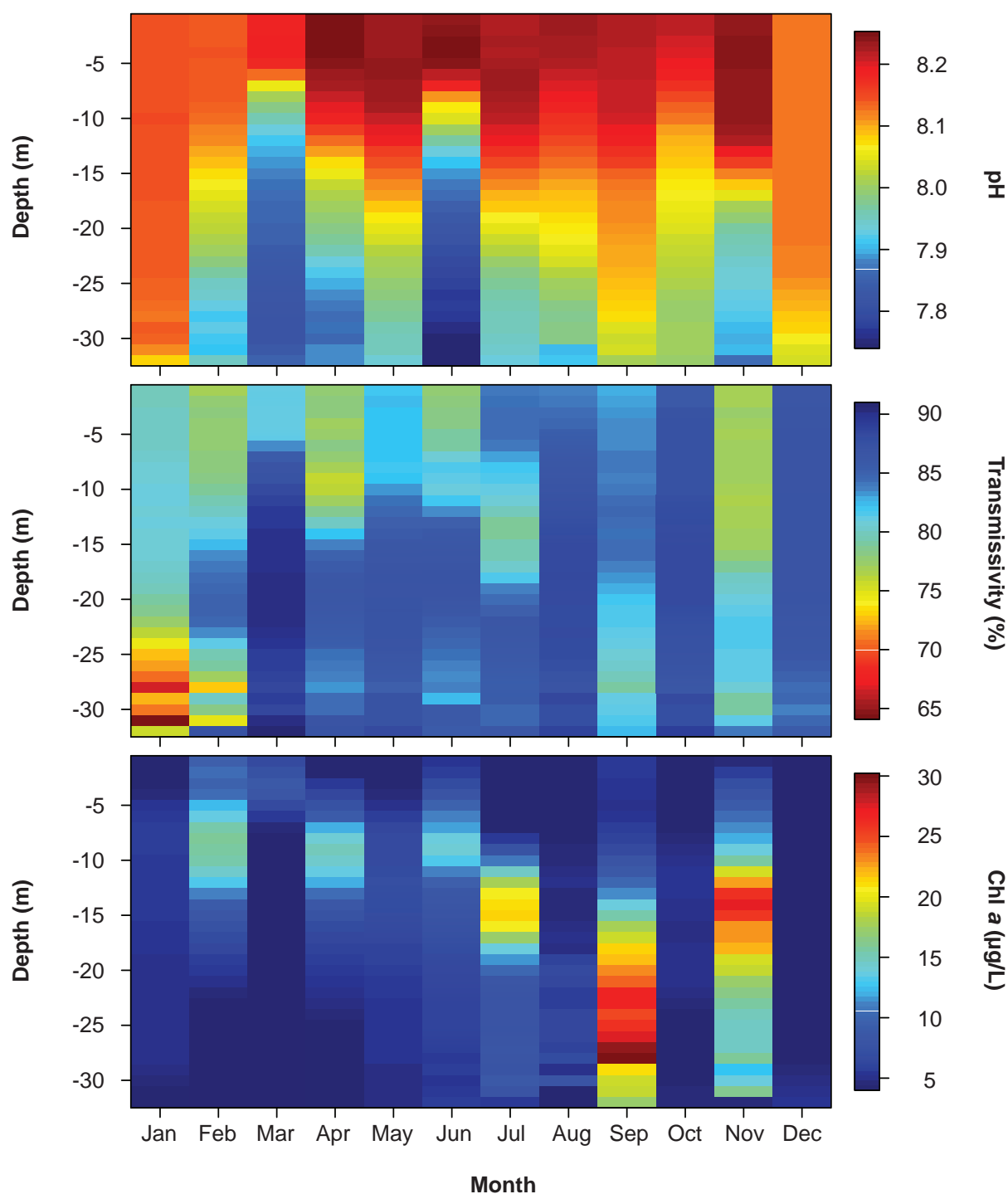


Figure 2.2 *continued*

of upwelling (e.g., $<12^{\circ}\text{C}$ at 28-m stations) occurred during the spring, with the lowest temperatures of the year recorded in March and June (Figure 2.2, Figure 2.3, Appendix A.1). Thermal stratification of the water column also varied as expected, ranging from mixed in the winter, to highly stratified in the summer, to less stratified in the fall. Since temperature is the main contributor to

water column stratification in southern California (Dailey et al. 1993, Largier et al. 2004), differences between surface and bottom temperatures were important to limiting the surfacing potential of the wastewater plume during certain times of the year. Results from remote sensing observations indicated presence of the plume in surface or near-surface waters during January, February, March,

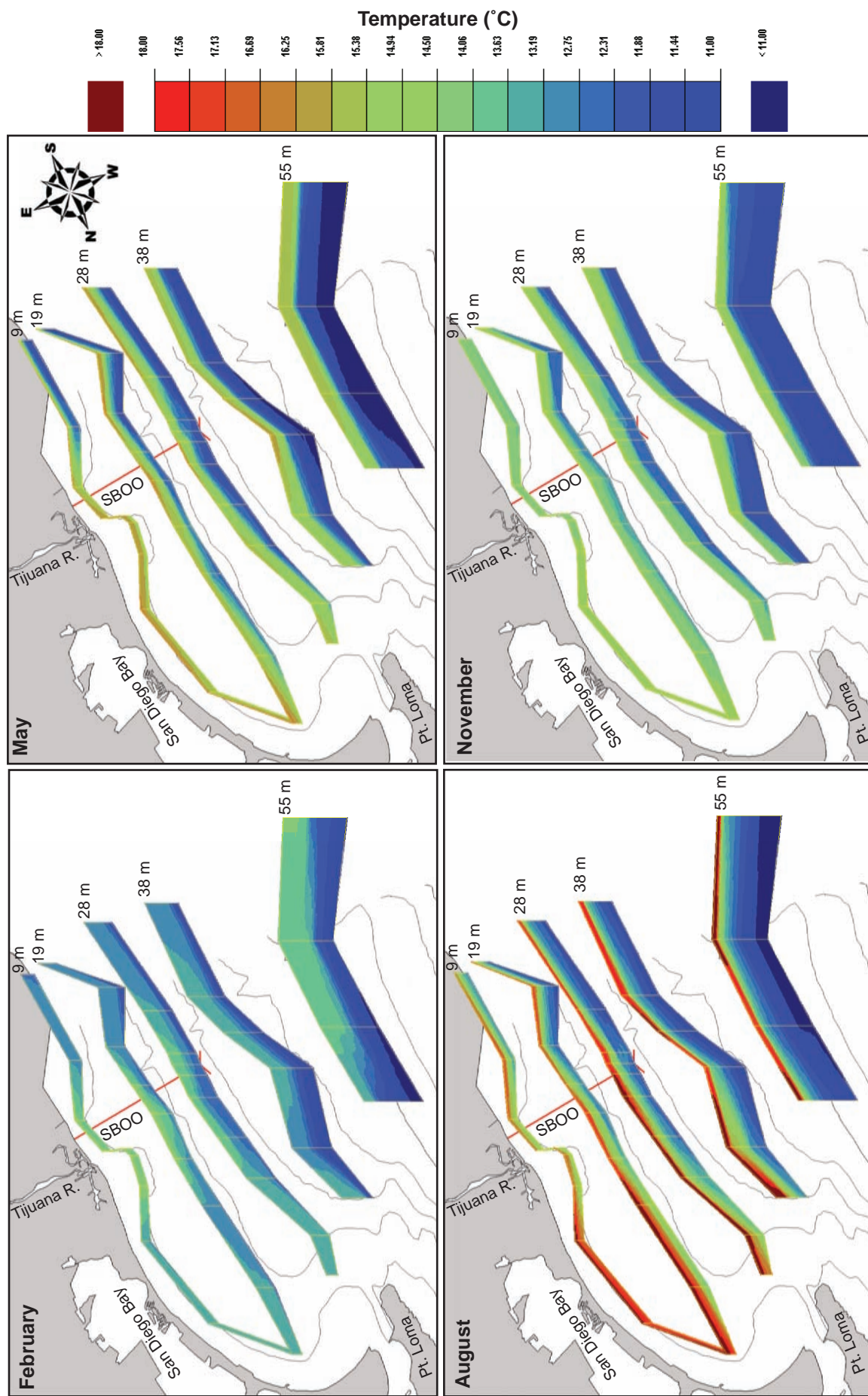


Figure 2.3

Ocean temperatures recorded in 2011 for the SBOO region. Data were collected over three consecutive days during each of these surveys. See Table 2.1 and text for specific dates and stations sampled each day.

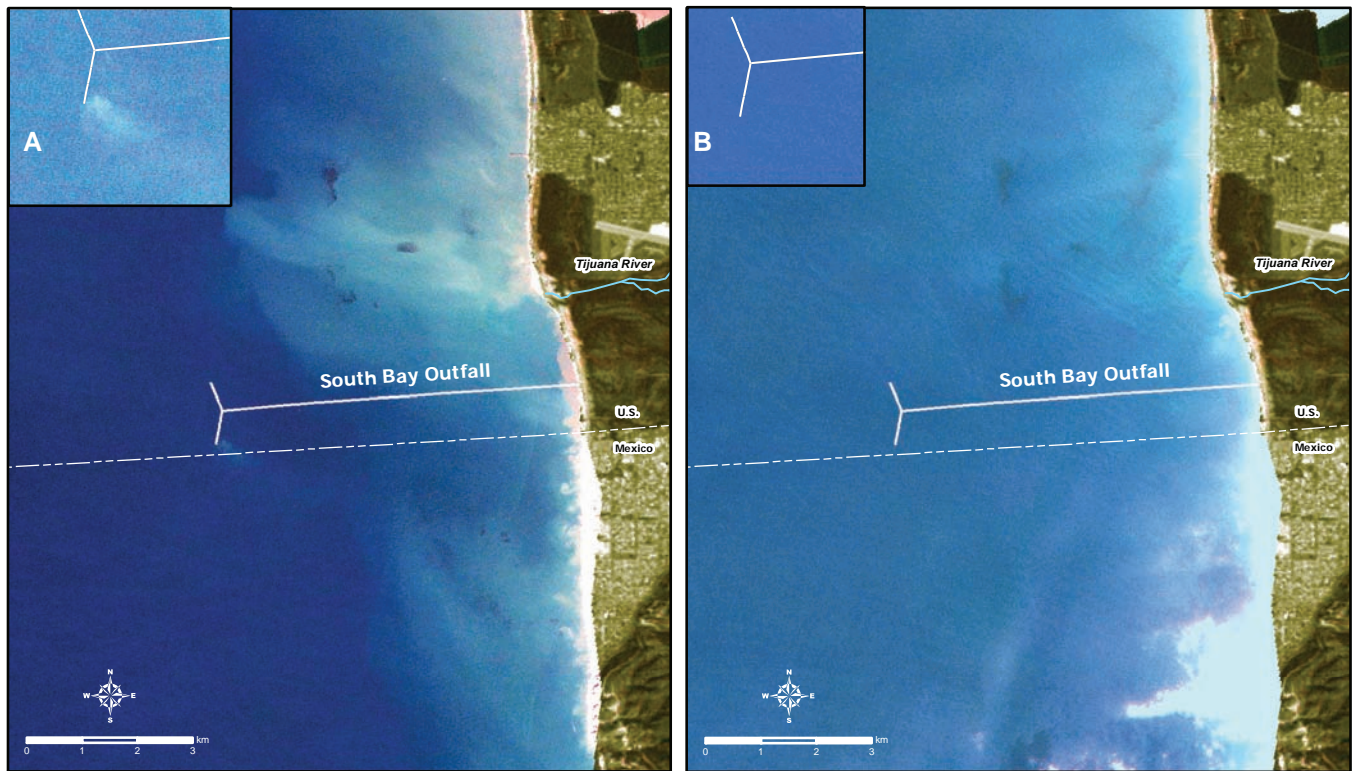


Figure 2.4

Rapid Eye images of the SBOO and coastal region acquired on December 21, 2011, demonstrating when the SBOO plume is visible at the surface (left; inset A), and on October 26, 2011, demonstrating when the SBOO plume is submerged under the thermocline (right; inset B) (see text; images from Ocean Imaging 2012).

October, November and December when the water column was more mixed, but not between April and September when the water column was stratified enough to keep the plume submerged (e.g., Figure 2.4; see also Svejksky 2012). Satellite observations also showed the furthest extent of the visible plume to be about 700 meters from the discharge area and was not likely to have reached the shoreline.

Salinity

Average salinities for the SBOO region in 2011 ranged from a low of 33.21 psu in March to a high of 33.60 psu in July for surface waters, and from 33.21 psu in October to 33.87 psu in June at bottom depths (Appendix A.1). Salinity also varied as expected by season, with the narrow range of values during January and December reflecting mixed conditions during these months. Additionally, relatively high salinity values were present across most of the region at bottom depths from March to July, with the highest values recorded during

March and June at stations along the 19, 28, 38, and 55-m stations (Appendix A.1). For example, salinity values were ≥ 33.49 psu at the 28-m stations during these months (Figure 2.2, Appendix A.1). Higher salinity values tended to correspond with lower temperatures found at bottom depths as described above. Taken together, these factors are likely indicative of local coastal upwelling typical for this time of year (Jackson 1986).

As in previous years, a thin layer of relatively low salinity values was evident at sub-surface depths during the spring, summer, and fall of 2011 (e.g., Figure 2.2, Figure 2.5). For example, salinity values were below about 33.37 psu between ~10 and 20 m depths at the 28-m contour stations during August (Figure 2.2). It seems unlikely that this sub-surface low salinity layer (SSL) is related to SBOO discharge for several reasons. First, no evidence has ever been reported of the plume extending simultaneously throughout the region in so many directions. Instead, previous remote

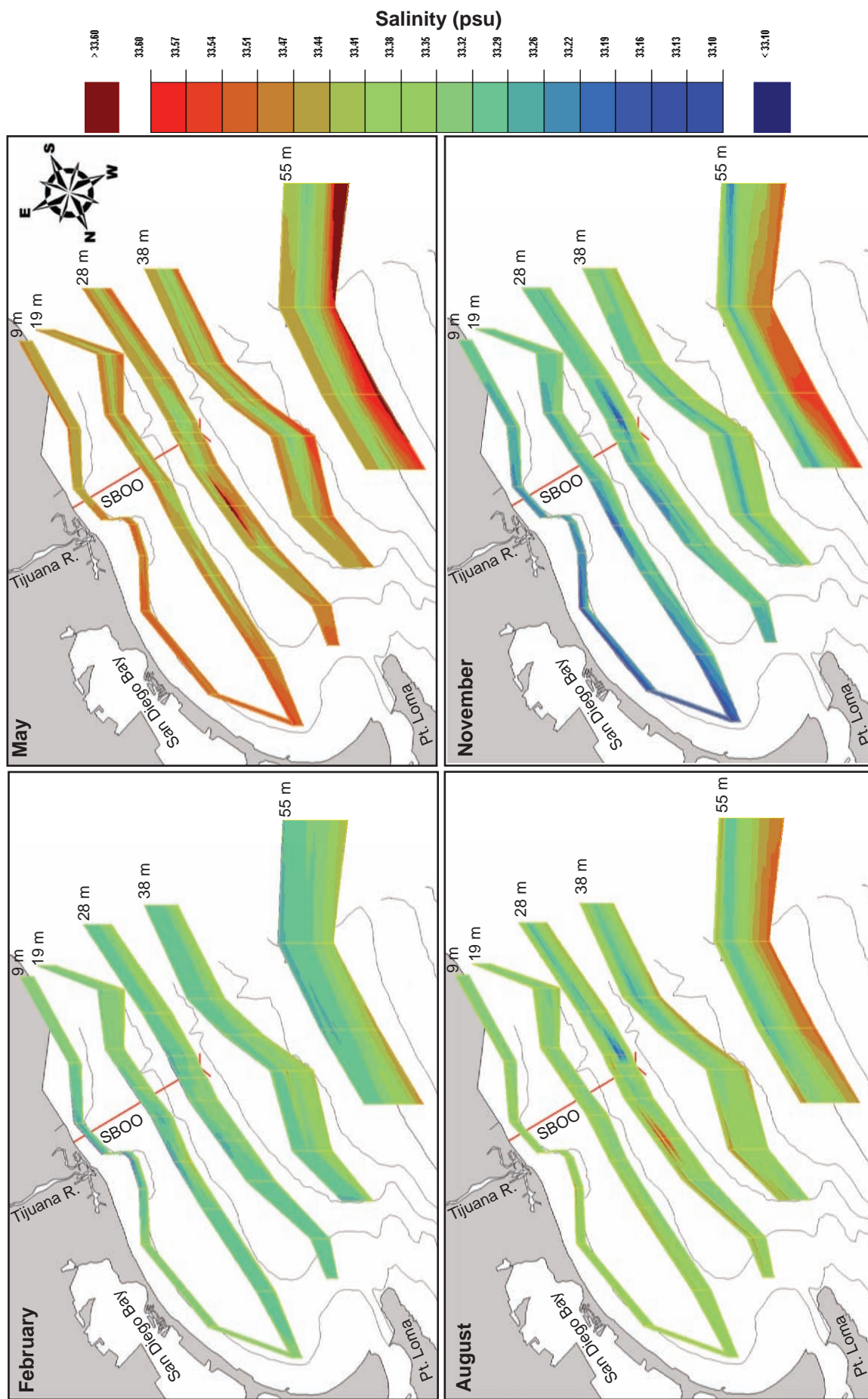


Figure 2.5

Ocean salinity recorded in 2011 for the SBOO region. Data were collected over three consecutive days during each of these surveys. See Table 2.1 and text for specific dates and stations sampled each day.

sensing observations (Svejkovsky 2010) and other oceanographic studies (e.g., Terrill et al. 2009) have demonstrated that the SBOO plume disperses in one specific direction at any given time (e.g., south, southeast, north). Second, similar SSLs have been reported previously off San Diego and elsewhere in southern California, including: (a) the Point Loma monitoring region during 2009, 2010 and 2011 (City of San Diego 2010a, 2011b, 2012); (b) coastal waters off Orange County for many years (e.g., OCSO 1999); (c) coastal waters extending as far north as Ventura County (OCSO 2009). Further investigations are required to determine the possible source(s) of this phenomenon.

When compared to the region-wide phenomena described above, salinity levels were found to be even lower at a few stations located near the SBOO discharge area at mid-water depths during almost every survey. For example, salinity values at station I12 were <33.33 psu between 10–13 m depths in May, <33.26 psu between 14–21 m depths in August, and <33.23 psu between 12–16 m depths in November (Figure 2.5). The lowest salinity reported at I12 during these months was as much as 8 psu lower than the lowest salinity recorded for nearby 28-m stations (e.g., I9, I14, I16, and I22). These relatively low salinity values were likely indicative of the SBOO wastewater plume, and are corroborated by relatively high CDOM values at station I12 during the same months (e.g., Figure 2.6).

Dissolved oxygen and pH

DO concentrations averaged from 7.3 to 10.1 mg/L in surface waters and from 3.3 to 9.1 mg/L in bottom waters across the South Bay outfall region in 2011, while pH values averaged from 8.0 to 8.3 in surface waters and from 7.7 to 8.2 in bottom waters (Appendix A.1). Changes in pH were closely linked to changes in DO (e.g., Figure 2.2) since both parameters tend to reflect the loss or gain of carbon dioxide associated with biological activity in shallow waters (Skirrow 1975). Similar distributions of both DO and pH values across all stations and along each depth contour indicate that the monthly surveys were synoptic even though

sampling occurred over a 3-day period (Table 2.1, Appendices A.2, A.3).

Stratification of the water column followed normal seasonal patterns for DO and pH, with the greatest variations and maximum stratification occurring predominantly during the spring and summer (e.g., Figure 2.2, Appendices A.2, A.3). Low DO and pH values at mid- and deeper depths during spring months were likely due to cold, saline and oxygen poor ocean water moving inshore during periods of local upwelling as described above for temperature and salinity. Concentrations of DO and pH were also very low at bottom depths during November, but these values did not correspond to lower temperatures or higher salinity values. Changes in DO and pH levels relative to wastewater discharge were not discernible during the year.

Transmissivity

Transmissivity appeared to be within historical ranges in the SBOO region during 2011 with average values of 46–88% on the surface and 47–91% in bottom waters (Appendix A.1). Water clarity was consistently greater at the offshore monitoring sites than in nearshore waters by as much as 43%, and changes in transmissivity levels relative to wastewater discharge were not discernible during the year. Instead, lower transmissivity along the 9, 19 and 28-m depth contours during the winter and fall months (Figure 2.2, Appendix A.4) may have been caused by wave and storm activity stirring up bottom sediments or particulate-laden runoff. For example, remote sensing observations revealed substantial turbidity plumes throughout the study area on January 1, 2011 and again on February 21, 2011 following major rain events (Figure 2.7). The turbidity plume that occurred during February was massive enough to extend past the end of the SBOO, and corresponded to lower water clarity that reached at least as far as the 38-m stations at surface depths (Appendix A.4). In previous years, reductions in water clarity have also co-occurred with peaks in chlorophyll concentrations associated with phytoplankton blooms (e.g., City of San Diego 2011a, Svejkovsky 2011). During 2011, this relationship was most apparent during February,

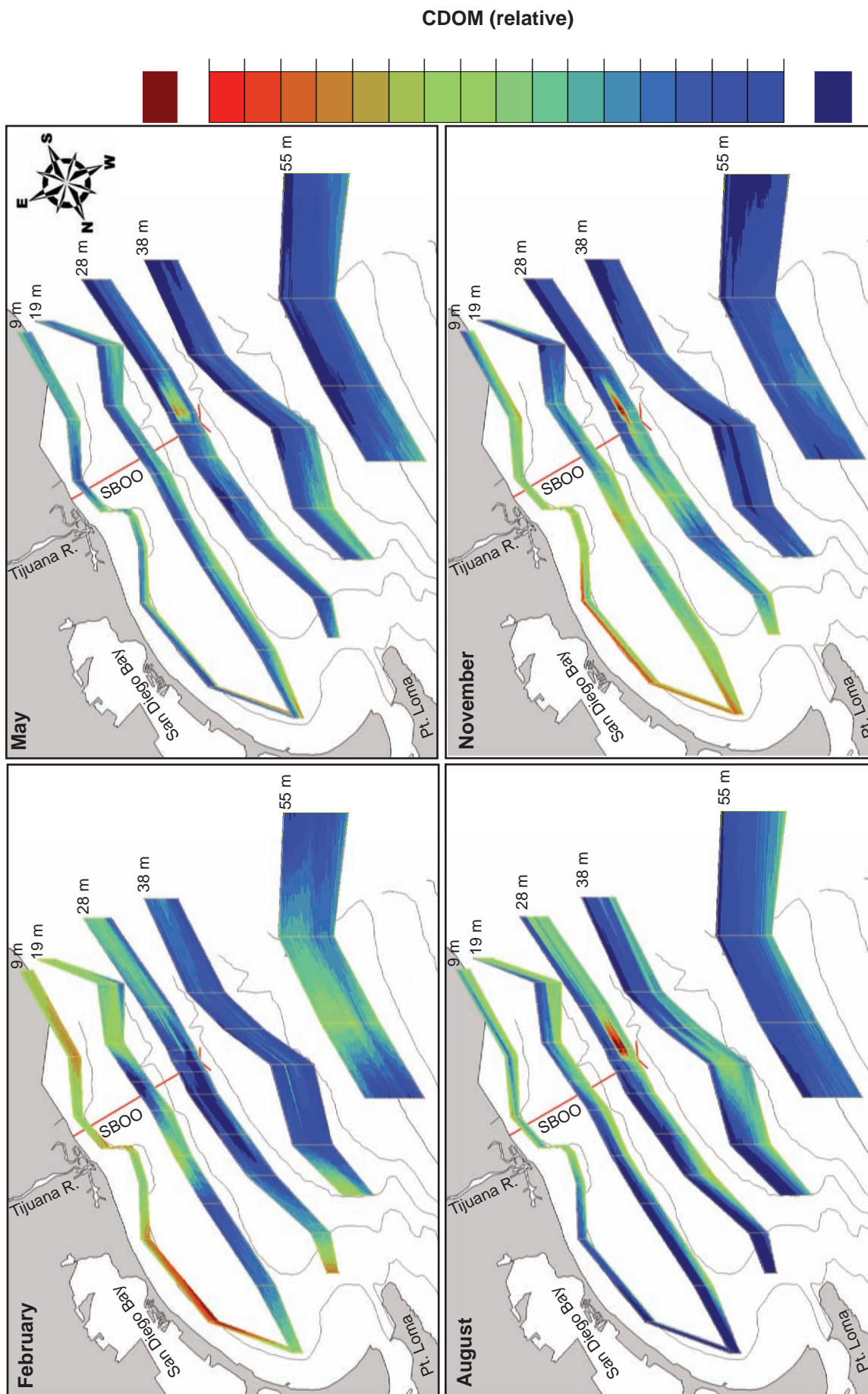


Figure 2.6 Relative CDOM values recorded in 2011 for the SBOO region. Data were collected over three consecutive days during each of these surveys. See Table 2.1 and text for specific dates and stations sampled each day. For each month, the highest value recorded is set as dark red and the lowest as dark blue.

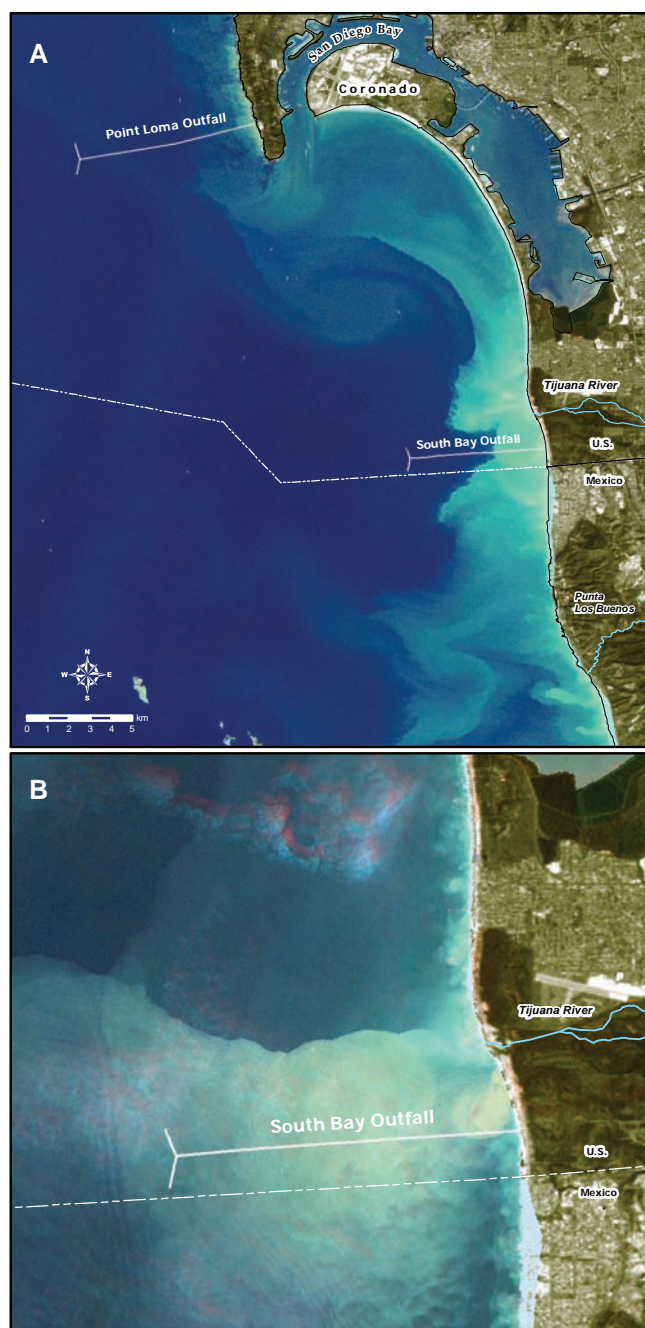


Figure 2.7

Rapid Eye images of the SBOO and coastal region depicting turbidity plumes in the study area following storm events on January 1, 2011 (top) and February 21, 2011 (bottom) (from Ocean imaging 2012).

April, June, July, September and November (e.g., Figure 2.2, Appendices A.4, A.5).

Chlorophyll a

Surface concentrations of chlorophyll *a* averaged from 1.7 mg/L in December to 10.7 mg/L in June, while chlorophyll concentrations in bottom waters

averaged from 0.4 mg/L in March to 26.9 mg/L in September (Appendix A.1). However further analysis clearly showed that the highest chlorophyll values tended to occur at mid- and deeper depths (e.g., Figure 2.2, Appendix A.5), reflecting the fact that phytoplankton tend to mass at the bottom of the pycnocline where nutrient levels are greatest (Lalli and Parsons 1993). The highest concentrations of chlorophyll occurred at these mid-depths during June, July, September, and November, primarily along the 19, 28, and 38-m depth contours (Appendix A.5; see also Figure 2.2). Seawater samples collected during the spring indicated a predominance of chain-forming diatoms in the genera *Chaetoceros*, *Pseudo-nitzschia*, and *Guinardia*, whereas samples collected during the fall were dominated by the dinoflagellate *Lingulodinium polyedrum*. The latter corresponds to the extensive dinoflagellate bloom observed by satellite that occurred throughout the San Diego region during September 2011 (Figure 2.8). In contrast to previous years, the occurrence of phytoplankton blooms in the SBOO region did not correspond as strongly to local upwelling events that were most evident between March and July (see above). A possible explanation for this disconnect is that several of the major phytoplankton blooms that occurred during 2011 off San Diego originated along the north county coast or Orange County and then spread southward, at times extending into the South Bay outfall region (Svejkovsky 2012).

Historical Assessment of Oceanographic Conditions

A review of oceanographic data from all stations along the 28-m depth contour sampled between 1995 and 2011 did not reveal any measurable impact that could be attributed to the beginning of wastewater discharge via the SBOO in January 1999 (Figure 2.9). Instead, these data tend to track long-term trends in the SCB, including conditions associated with the El Niño Southern Oscillation (ENSO), Pacific Decadal Oscillation (PDO), and North Pacific Gyre Oscillation (Peterson et al. 2006, McClatchie et al. 2008, 2009, Bjorkstedt et al. 2010, 2011, NOAA/NWS 2011). For example, six major



Figure 2.8

Wide-spread phytoplankton blooms in San Diego's nearshore waters in the South Bay outfall region acquired with MODIS imagery September 8, 2011 (from Ocean Imaging 2012).

events have affected SCB coastal waters during the last two decades: (1) the 1997–98 El Niño; (2) a shift to cold ocean conditions reflected in ENSO and PDO indices between 1999–2002; (3) a subtle but persistent return to warm ocean conditions in the California Current System (CCS) that began in October 2002 and lasted through 2006; (4) intrusion of subarctic waters into the CCS that resulted in lower than normal salinities during 2002–2004; (5) development of a moderate to strong La Niña in 2007 that coincided with a cooling of the PDO; (6) development of a second La Niña starting in May 2010. Temperature and salinity data for the South Bay outfall region are consistent with all but the third of these events; i.e., while the CCS was experiencing a warming trend that lasted through 2006, the SBOO region experienced cooler than normal conditions during 2005 and 2006. The conditions in southern San Diego waters during these two years were more consistent with observations from northern Baja California (Mexico) where water temperatures were

well below the decadal mean (Peterson et al. 2006). Further, below normal salinities that occurred after the subarctic intrusion were likely associated with increased rainfall (Goericke et al. 2007, NWS 2011). During 2011, temperatures remained colder than normal through the end of the year.

Water clarity (transmissivity) has generally remained of high-quality in the South Bay outfall region since wastewater discharge began in 1999, although there have been several intermittent periods when clarity was below normal (Figure 2.9). As discussed in the previous section, periods of low transmissivity during winter and late fall may have been caused by wave and storm activity that stirred up bottom sediments or particulate-laden runoff, whereas decreased transmissivity during the spring, summer or early fall may have been related to phytoplankton blooms.

There have been no apparent long-term trends in DO concentrations or pH values related to the SBOO discharge (Figure 2.9). Instead, there have been several periods during which lower than normal DO and pH values aligned with low water temperatures and high salinity, thus indicating the cold, saline and oxygen poor ocean water associated with local coastal upwelling as discussed above (e.g., 2002, 2005–2011).

SUMMARY AND CONCLUSIONS

Oceanographic data collected in the South Bay outfall region concur with reports that describe 2011 as a La Niña year for the CCS characterized by the early onset of relatively strong upwelling (Bjorkstedt et al. 2011). For example, colder-than-normal sea surface temperatures were observed during summer months as would be expected during La Niña conditions; these results were evident in data collected by the City and corroborated by remote sensing observations (Svejkovsky 2012). Conditions indicative of local coastal upwelling, such as relatively cold, dense, saline waters with low DO and pH levels at mid-depths and below, were observed during the spring, but were most evident

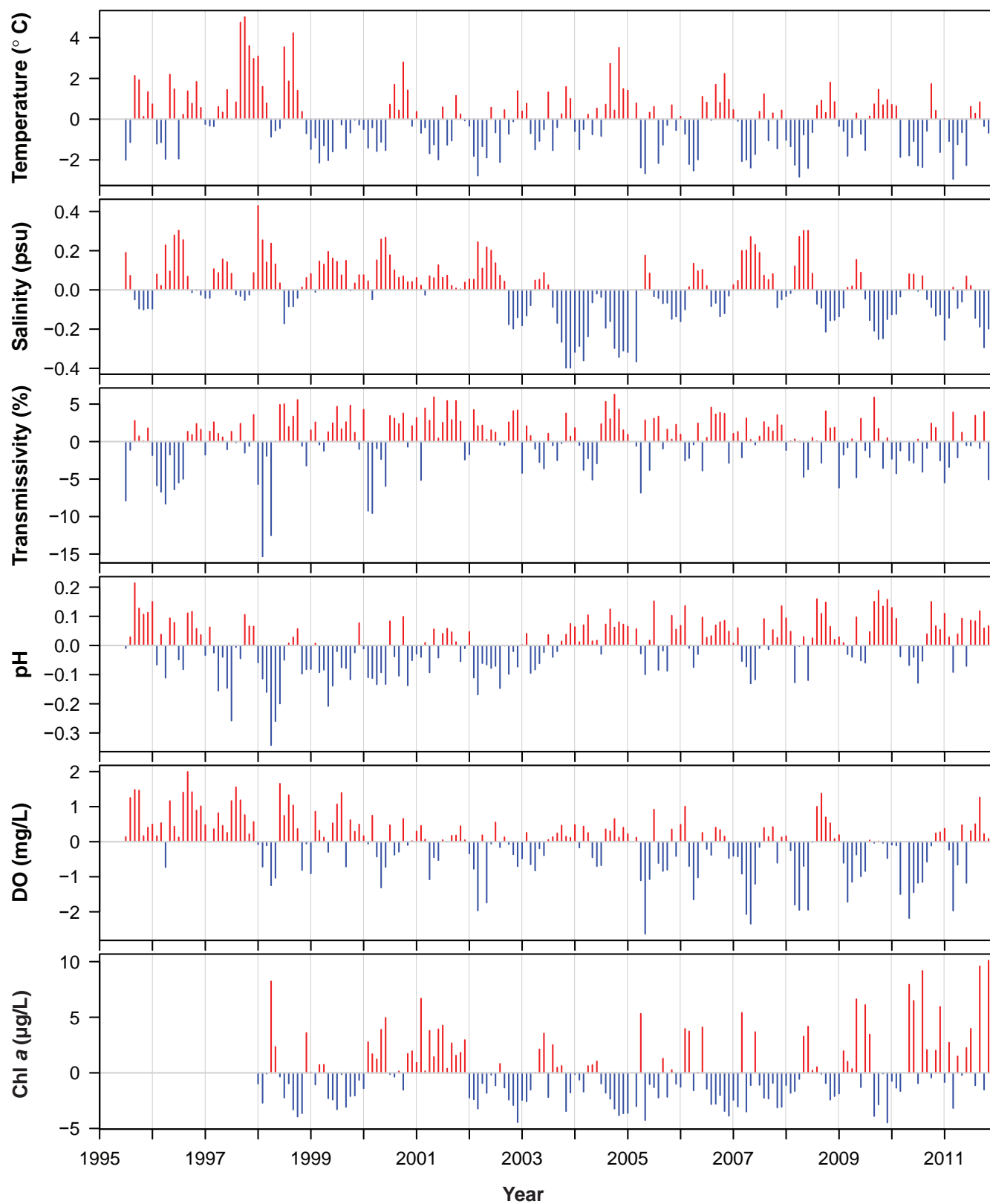


Figure 2.9

Time series of temperature, salinity, transmissivity, pH, dissolved oxygen (DO), and chlorophyll a (Chl a) anomalies between 1995–2011. Anomalies were calculated by subtracting means for all years combined (1995–2011) from monthly means of each year; data were limited to all stations located along the 28-m depth contour, all depths combined.

during March and June. Phytoplankton blooms, indicated by high chlorophyll concentrations and confirmed by satellite imagery were present throughout the region during much of the year. Additionally, water column stratification followed typical patterns for the San Diego region, ranging from mixed waters during the winter, to highly stratified waters in the summer, to less stratified in the fall. Further, oceanographic conditions were consistent with long-term trends in the SCB (Peterson et al. 2006, McClatchie et al. 2008, 2009, Bjorkstedt et al. 2010, 2011, NOAA/NWS 2011) or with data from northern Baja California (Peterson et al. 2006). These observations suggest that other factors such as upwelling of deeper offshore waters and large-scale oceanographic events (e.g., El Niño, La Niña) continue to explain most of the temporal and spatial variability observed in oceanographic parameters off southern San Diego.

As expected, results of satellite imagery detected the presence (signature) of the SBOO wastewater plume in near-surface waters over the discharge site on several occasions between January–March and October–December when the water column was not strongly stratified (Svejkovsky 2012). Bacteriological sampling results for the same region described herein resulted in very few samples with elevated concentrations of fecal indicator bacteria in 2011 (see Chapter 3); the lack of bacteriological contamination was most likely due to initiation of full secondary treatment at the IWTP in January, 2011. Therefore, these data may no longer be useful for plume tracking. However, historical analysis of remote sensing observations made between 2003 and 2009 provided no evidence that the wastewater plume from the SBOO has ever reached the shoreline (Svejkovsky 2010). These findings have been supported in subsequent years of remote sensing reporting (Svejkovsky 2011, 2012) and by the application of IGODS analytical techniques to oceanographic data collected by the City’s ocean monitoring program for the past three years (City of San Diego 2010b, 2011a). For example, although small salinity differences have been observed at stations close to the outfall discharge site, and corroborated by relative CDOM data this year, it

was clear from all analyses that variations among stations at any particular depth were very slight and highly localized. Further, high resolution satellite images suggest that the wastewater plume typically remains within approximately 700 m of the outfall.

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